Decentralizing Science: Towards an Interoperable Open Peer Review Ecosystem using Blockchain.

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Abstract

Science publication and its Peer Review system strongly rely on a few major industry players controlling most journals (e.g. Elsevier), databases (e.g. Scopus) and metrics (e.g. JCR Impact Factor), while keeping most articles behind paywalls. Critics to such system include concerns about fairness, quality, performance, cost, unpaid labor, transparency, and accuracy of the evaluation process. The Open Access movement has tried to provide free access to the published research articles, but most of the aforementioned issues remain. In such context, decentralized technologies such as blockchain offer an opportunity to experiment with new models for science production and dissemination relying on a decentralized infrastructure, aiming to tackle multiple of the current system shortcomings. This paper makes a proposal for an interoperable decentralized system for an open peer review ecosystem, relying on emerging distributed technologies such as blockchain and IPFS. Such system, named "Decentralized Science" (DecSci), aims to enable a decentralized reviewer reputation system, which relies on an Open Access by-design infrastructure, together with transparent governance processes. Two prototypes have been implemented: a proof-of-concept prototype to validate DecSci's technological feasibility, and a

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Preprint submitted to Journal of Information Processing and Management September 25, 2020

Minimum Viable Product (MVP) prototype co-designed with journal editors. In addition, three evaluations have been carried out: an exploratory survey to assess interest on the issues tackled, a set of interviews to confirm the main problems for editors, and another set of interviews to validate the MVP prototype. Additionally, the paper discusses the multiple interoperability challenges such proposal faces, including an architecture to tackle them. This work finishes with a review of some of the open challenges that this ambitious proposal may face.

Keywords: blockchain, decentralized systems, distributed systems, open access, open peer review, peer review

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1. Introduction

In the last decades, the Internet has revolutionized multiple fields. However, the production of science and its peer review process have not seen large changes with respect to the traditional paper-based publication and review practices [1]. The communication of knowledge still relies on academic articles, that journals collect and publish with certain periodicity for the consumption of scholars in academic institutions. The criticisms to nowadays scientific publication and peer review processes include concerns with respect to quality [2], fairness [3], cost [4], performance [5], and evaluation metrics accuracy [6].

Still, the advent of the Internet brought some changes to the scientific process. Its reduction of distribution costs allowed for broader access to scientific knowledge, and thus further questioning the role of traditional publishers which previously assumed the distribution effort [7]. Thus, alternatives emerged, especially with respect to Science dissemination, i.e. Open Access [8]. The Open Access movement, leveraging the replicability of digital content, aims to provide free access to the published research articles. And even though it is far from universal, it is generally recognized that the Open Access movement has achieved to decrease the economic cost for readers to access knowledge [9].

However, despite its partial success, its potential to democratize access to knowledge has been questioned [10], since it has not successfully challenged traditional publishers' business models [11] which are often charging both readers and authors [12].

With respect to the traditional peer review system, despite the multiple criticisms received mentioned above, only few alternatives have gathered success [13, 14]. The literature provides multiple proposals around "open" peer review [15], which would enable transparent and public reviews, versus the traditional blind and private reviews [16]. In fact, relying on such open peer review models, we can find some proposals of reputation networks for reviewers [17], which may provide new quality control processes for the reviewers, authors and editors. It is worth noting that the start-up Publons[1], provides a platform to acknowledge reviews and open them up. The project reached quickly a large reviewer community, and it was recently absorbed by Clarivate Analytics publishing conglomerate.

In the last decades, other initiatives that challenge the traditional science publication process have emerged. *Preprints* are versions of scientific articles which have undertaken formal peer review, and have not been published formally in a journal or conference proceedings. Today, there are multiple widely successful platforms to host preprints and provide them visibility, like arXiv[2] or Preprints.org[3] [18].

Besides, social networks crafted for the scientific community have also found their niche. These enable scientists to upload their authored published articles, sharing them with fellow scientists whom they can connect. Example successful platforms include Academia[4] or Research Gate[5].

These platforms are all centralized, that is, relying on a single platform owner which controls the infrastructure. Such centralization has multiple consequences

[1] https://publons.com/
[2] https://arxiv.org/
[3] https://www.preprints.org/
[4] https://www.academia.edu/
[5] http://researchgate.com/

[19, 20, 21] for example, problems related to monopolistic business models which affect users and their data; the need to depend on and trust a third-party which may change its policies anytime (e.g. in case of a change of business model, or a buy-in); market dominance over derived services such as metrics (e.g. JCR Impact Factor) or databases (e.g. Scopus); paywalls and the derived need of subscription packages for research institutions; and overall, issues related with the lesser control of researcher community over their data and processes.

Decentralized alternatives potentially improve a wide variety of science publication and peer reviewing issues [22]. Proposals use different blockchain affordances [23] to improve science publication. The transparency and inmutability of blockchains is used to assert the time of existence and authorship of data and documents [24]. *Crypto-tokens*, i.e. transferable electronic representations of value (such as currency or permissions), are used to incentive collaboration [25], management of data access permissions [26], reproducibility of studies [27], or peer reviewing [28, 29] and other ways of endorsement of publications [30], as well as to propose new methods of funding research [31]. The openness and transparency of blockchains is used to enhance Open Access [32], Open Science practices [33], and transparency in publishing and funding processes [34]. Finally, *smart contracts*, i.e. software that is automatically executed in a decentralized blockchain network, are used to provide automatic processes for science publication [35, 25], or reproducibility of studies and experiments [36].

This paper proposes the development of a decentralized publication and peer review system relying on an Open Access and open review model. This work joins other initiatives in challenging the current infrastructure that supports what it is considered an oligopoly of traditional publishers [11].

As mentioned above, the Open Access movement has enabled a portion of academic publications to remain freely available. However, these publications are still mostly served from infrastructure controlled by a few industry players (Elsevier, Springer, Clarivate). Thus, infrastructure ownership enables them to exert control, impose policies (e.g. limitations to dissemination, copyright transfer, Open Access fees price, embargo periods) and concentrate profits [37].

The system proposed in this work, named "Decentralized Science" aims to enable the scientific community to hold higher control over their infrastructure. Thus, the proposal involves to decentralize 3 main parts of the scientific process:

- The process of selecting reviewers and recognizing their work, through the use of a reviewer reputation system in which review reports may be rated.
- The (server-less) research dissemination, by distributing academic articles through the IPFS peer-to-peer network, and by default provisioning an Open Access by-design infrastructure.
- The transparency of the whole peer review process, through the use of blockchain technologies. Thus, review reports will be public following the open peer review model [15], together with the communication flow from paper submission to reviewer proposals and review submissions.

Concerning specifically with the peer review process, the proposed system tackles four issues: the overall quality of the reviews; the fairness of the process for the authors; the fairness of recognition (and payment) for reviewers; and the challenges associated with the search and selection of good reviewers for the journal editors.

To achieve such an ambitious goal and taking into account that our proposal uses distributed technologies that are not mature yet, we have decided to use an iterative and incremental approach building partial prototypes that allow us to validate their viability. These prototypes are the result of various interviews with other interested parties, that have subsequently participated in their validation. Furthermore, for our proposal to be successful, it must be able to inter-operate with other existing platforms (centralized or decentralized), which represents significant challenges. This paper extends our previous work [32] in several ways: 1) it delves into the fundamental requirements that give value to our proposal, 2) it extends the system architecture and describes a first prototype search tool to find reviewers that has been co-designed and validated with journal editors, and 3) it analyzes the interoperability challenges faced by our platform to integrate and collaborate with other existing platforms and technologies.

The rest of the paper is organized as follows. First, Section 2 reviews the main decentralized technologies used, together with related concepts. Section 3 describes the main requirements for the system, which is later designed in Section 4. Following, Section 5 describes two software prototypes: 1) a proof of concept to assess the technological feasibility of the proposal (Subsection 5.1) and 2) a minimum viable product for the management of peer reviewing (Subsection 5.2). Section 6 presents the evaluation of the system, consisting of two studies, a survey to evaluate the perception of the problems and proposed solutions (Subsection 6.1), and a series of interviews to evaluate the relevance of the problem and adequacy of the prototype to solve them (Subsection 6.2). Additionally, Section 7 discusses the challenges to integrate decentralized applications with existing technologies and online communities. To conclude, Section 8 tackles the main challenges and open questions that this proposal entails.

2. The Decentralized Technologies Used

The use of decentralized technologies is an essential part of our proposal to provide transparency and accountability throughout the scientific paper publication process (submission, revision, publication and access) and, at the same time, avoid the concentration of power in a few actors. Using these technologies to implement the core of the platform we ensure that every fundamental transaction in the system will be publicly recorded and validated by a majority of the network participants according to a pre-established set of rules. This way, none of the participants has more decision power than the others because the transactions in the platform are accepted or rejected using a majority consensus mechanism. Furthermore, the public and permanent log of these transactions promotes transparency and trust in the process. Next, we introduce the main distributed technologies on which our proposal is based.

IPFS [38] is a peer-to-peer hypermedia protocol that enables the distribution of files using a decentralized network. Files are divided in blocks that are indexed using cryptographic hashes. These blocks are then distributed (and possibly replicated) among the network nodes. When a file needs to be retrieved, its blocks can be downloaded simultaneously from different peers. Note that new participants can add new nodes to the network and replicate the content they are interested in. We propose the use of IPFS to store and share the different versions of the papers, from first drafts to final versions, and peer review reports.

Blockchain is the underlying technology that supports Bitcoin [39], the first fully distributed digital currency. Monetary transactions are collected in blocks that are accepted or rejected by the peer network using a consensus mechanism in which at least half of the network needs to agree. Each new block is then linked to the previous one creating an inmutable chain of blocks (blockchain) or public ledger that contains all the historical transactions performed. It is interesting to mention that each node of the network stores a full copy of the blockchain so that it can autonomously accept or reject future transactions. The order in which transactions are recorded in the public ledger is decided by the node (miner) that produces the next valid block. In order to produce new blocks, the nodes compete against each other to solve a computationally expensive problem. This computational effort is rewarded by the protocol with incentives (new bitcoins) to maintain the security of the ledger.

Ethereum [40] extends the blockchain technology to enable to execution of small programs or *smart contracts* creating the first blockchain-based distributed computing platform. These smart contracts are stored in the blockchain (so they are immutable) and triggered using transactions that define which part of the program must be executed. Similarly to the Bitcoin blockchain in which all the nodes validate the bitcoin transactions, in Ethereum all the nodes execute the same smart contracts to reach a majority consensus regarding the changes they produce in the public ledger that defines the state of the network. Each smart contract, therefore, defines a set of rules based on its code and once they are deployed they can be executed autonomously. In summary, smart contracts are interesting because they allow the transparent execution of immutable programs in a trustless network. Some examples of Ethereum-based decentralized applications are prediction markets [41] or social networks [42]. We propose the use of smart contracts to enforce transparency throughout the peer review process and to implement a reviewer reputation system.

3. The Proposal Requirements

The proposed system, named "Decentralized Science" (abbreviated DecSci), aims to provide a decentralized platform for the scientific process, from submission to publication, with a special attention to the peer review process. It relies on three pillars, which are covered in this section: a decentralized reviewer reputation system, an Open Access by-design infrastructure, and a transparent governance.

3.1. A Distributed Reviewer Reputation System

Typically, a major issue for editors and journals is accumulating the knowledge on the reliability and quality of reviewers. This valuable data is often kept private to publishers and their journals, reinforcing their influential positions. In fact, it is hard to predict the quality of a potential reviewer, even with knowledge on their training and past experience [43].

DecSci incoportates a new element to the traditional peer review communication work-flow: the option to rate the reviews, and then building metrics around those ratings, providing a reviewer reputation system [44]. Thus, this opens the possibility for reviewers to be rewarded or penalized depending on the quality, fairness or speed of their reviews.

Building an open and public reputation system has multiple benefits for reviewers, including recognition and visibility [45], but also monetary incentives e.g. through cryptocurrencies [46]. Besides, such open system is expected to reduce biased and unfair reviews, due to public exposure [3, 47].

3.2. Open Access By-Design

Open Access refers to the principles and practices in which research outputs are distributed online, free of cost or other access barriers.[6] Thus, through the growth of Open Access, publishers provide research articles freely to readers. However, as mentioned above, since publishers are also the owners of the dissemination infrastructure, they are capable to establish certain rules and restrictions. For instance, they may charge authors unreasonable fees to opt for the Open Access option [48], or demand restrictions or year-long embargoes for disseminating the final version [49].

The DecSci proposal involves a decentralized infrastructure also to store and host all the documents involved in the scientific process. Thus, the different versions of the research paper, together with its reviews, are deployed publicly through the IPFS peer-to-peer network [38] (see Section 2). In such network, it is significantly hard to restrict access to the provided documents. Therefore, the proposed system implicitly enables unrestricted Open Access, facilitated by its decentralized infrastructure. This is designed in order to avoid dominant market positions such as those mentioned by current publishers. In fact, in case DecSci stopped working, the uploaded documents would still remain available in the IPFS distributed network, and links to them would still work as usual.

3.3. Transparent Governance

As mentioned above, among the multiple issues of the current scientific process, there is a lack of transparency. That is, processes are typically private and closed, controlled by publishers, and depending on their infrastructure. Similarly, communications across authors, reviewers and editors remain private, and may enable arbitrary or biased results. [47].

DecSci aims to surpass these limitations through significantly increasing the

[6]We do not refer here to the Open Access strict definition in which it is required that the article is not only freely accessible, but also open-licensed, removing further barriers to copying or reuse (e.g. as in PLoS journals).

transparency of the processes involved, hoping to improve speed and fairness in parallel. Thus, it proposes to record in a public blockchain, i.e. a distributed ledger, the interactions concerning article submission/publication, reviewer assignment or review submission. Therefore, previously obscure processes such as the reviewer selection or the review reports, would be open publicly. In addition, blockchain time-stamps every interaction and provides a theoretically tamper-proof mechanism, and thus the processes can be monitored by third-parties, audited, and eventually held accountable.

More research would be needed concerning the effects of both open reviews and open communication process, since it may influence the dynamics and incentives for journals and not just for authors or reviewers. Nowadays, journals are penalized for accepting irrelevant papers (i.e. which will not be cited, or have low quality), but are not penalized for rejecting valuable papers [7, 50]. Thus, high rejection rates are typically encouraged. Within DecSci though, the latter would be also penalized, potentially triggering different dynamics for quality control and filtering.

Overall, we believe the transparent governance processes, combined with the decentralized infrastructure, enables experimentation and the emergence of novel work-flows [47].

4. System Design using a Decentralized Architecture

The DecSci platform aims to support the whole peer review process, from paper submission to acceptance or rejection, as well as the rating of peer reviews to build a reviewer reputation network. Our platform relies on the two decentralized technologies introduced in Section 2: IPFS and Ethereum Smart Contracts. On the one hand, *IPFS* provides a distributed file system to store and share documents such as the different versions of the paper, from first drafts to final versions, as well as the peer reviews generated during the revision process. On the other hand, *Ethereum Smart Contracts* are used to implement the rules of the system with transparency, such as only accepting reviews from invited reviewers, and register all the interactions in the blockchain. Note that the interactions are automatically time-stamped depending on the block in which they are accepted and cannot be tampered or deleted afterwards, creating a reliable log of the peer review process. Besides, this architecture provides free access and persistence to the registered information, and ensures its independence from centralized servers.

It is important to remark that, although DecSci relies on these novel technologies, users are not required to have any technical knowledge about them. Users interact with the platform using a web application that handles all this technical details for them, and users only need to have a valid identity in the network (an Ethereum address). For example, the sequence diagram shown in Figure 1 describes the main interactions during a peer review process and below we describe the basic ideas to implement them.

Paper submission When an author submits a new paper to the platform, the paper is automatically uploaded to the IPFS network so the IPFS address can be used as an unique identifier of the document. Next, the platform creates an Ethereum *smart contract* that will manage and record the peer review process for that specific paper. Note that the Ethereum transaction that creates the smart contact can be used to verify that the authors submitted the paper at some specific time. This smart contract will record the Ethereum addresses of the authors and journal editors.

Review proposal Journal editors may invite reviewers to review a specific paper, adding this *review request* to the paper's *smart contract.* This interaction records the reviewer's Ethereum address as well as an optional submission deadline for the review. The reviewer may respond accepting or rejecting the review request, in which case the editor can invite another reviewer.

Review submission When a reviewer submits a review, the document is automatically uploaded to the IPFS network. Then, the reviewer carries out

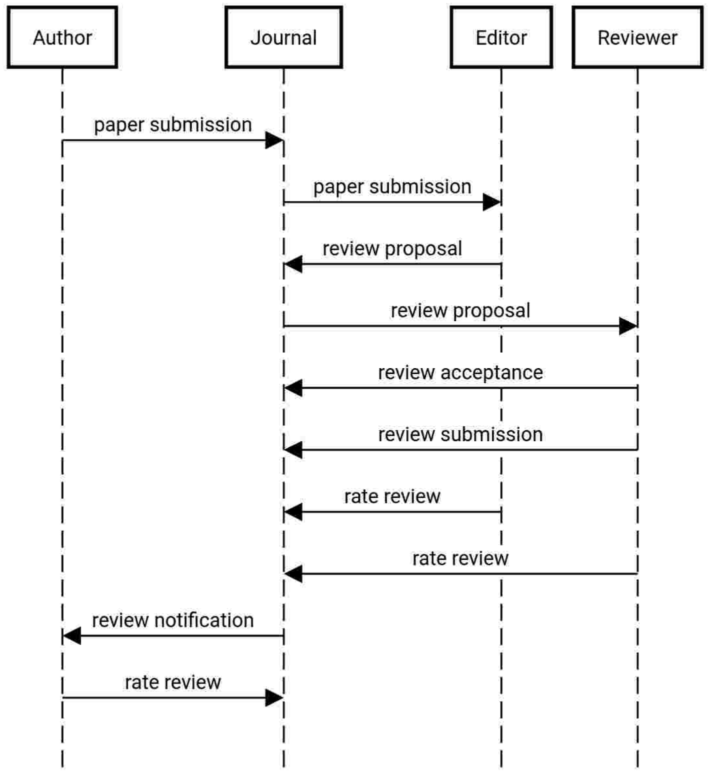

Figure 1: Sequence diagram of a peer review process.

an Ethereum transaction to the smart contract using the IPFS address of the review as well as her verdict (acceptance of rejection of the paper). In the event of a missing review or delay, a penalty can be applied to the reviewer's reputation in the reputation system.

Review rating Our proposal introduces a reputation system for reviews (Section 3.1). The actors involved in a peer reviewing process, i.e. the authors, editors and other reviewers, can rate the submitted review reports. These ratings are recorded in the blockchain.

One of the most important aspects to guarantee that the review process works correctly is to have a good base of reviewers who are willing to collaborate and whose knowledge and interests covers the different topics of the

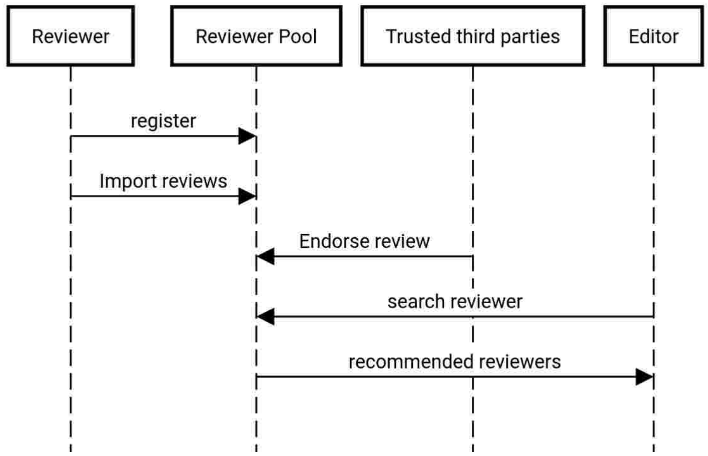

Figure 2: Sequence diagram of reviewer registration, endorsement and search.

journal. In order to create better matches between reviewers and submission and, therefore, increase the quality of the revision process, DecSci incorporates a reputation system for reviewers and provides a search tool for the editors. This search tool can be use to find good candidates according to their interests, previous reviews and reputation rates. Below we describe this interactions in the platform, Figure 2 provides a sequence diagram of these interactions.

Register as reviewer Interested reviewers only need an Ethereum address to register in the system. Their interests and areas of expertise are also stored in the blockchain and can be updated at any time.

Import review Reviewers can import their previous reviews to the system. Several reviewers already have profiles and reviews stored in other online communities such as Publons, post-publication peer review services such as F1000Research or Peerage of Science and Academic databases such as ORCID or Crossref. As explored in Section 7.3, integrations with such systems are being developed.

Endorse review As anybody can freely import their previous peer reviews, there is a need for applications to decide if these reviews can be trusted or not. The system enables a way for other actors to endorse the validity of the imported reviews. Section 7.4 offers a detailed discussion on how this system would be implemented.

Search reviewer Journal editors should be able to find the most relevant and better reviewers for each paper. In Section 5 we describe our work to provide a useful and intuitive web interface to facilitate this task and find reviewers with relevant research interests, showing relevant information about them such as their reputation, acceptance rate, timelines and previous reviews.

5. Implementation

In order to realize our system proposal, we have developed two distinct prototypes:

- First, a proof-of-concept prototype to validate the technological feasibility of the proposal. Such implementation enabled the performance of preliminary tests of each of the platform's interactions, and to validate the feasibility of our decentralized architecture for the implementation of the system. Thus, this prototype provides a simple version of the requirements specified in Section 3, and the interaction design from Section 4.

- Second, a Minimum Viable Product prototype for Reviewer Management, co-designed with journal editors. This functional software is focused on the most relevant functionalities that current journals require, and facilitate its integration with existing journal infrastructure. Thus, it focuses on a subset of Section 4 interactions, in particular those relevant for reviewer search and reviewer data (in order to extract quality metrics).

5.1. A Proof-of-concept to Validate Technical Feasibility

As explained above, this proof-of-concept prototype allows us to test the main interactions using the aforementioned decentralized technologies, namely

Ethereum, Smart Contracts and IPFS. This software implements a basic version of Section 3 requirements and Section 4 design. The software is publicly available as free/open source, available in Github[7].

Thus, this prototype architecture uses IPFS as a distributed file system to store and share the review reports and papers, and the Ethereum Blockchain to implement the logic of the system and to manage it's state. The prototype uses a Web interface that communicates with IPFS and Ethereum networks using JavaScript libraries. It proposes the use of Metamask[8] to provide user-friendly management of Ethereum identities.

This proof-of-concept prototype uses three different Ethereum smart contacts to run the platform's inner functioning. The *Journal* smart contract provides functionality for the submission of papers, the selection of editors, and the management of review requests. The *Paper* smart contract serves to provide a digital id for the papers, manages the submission of review reports, and specifies who is allowed to rate a review report. Finally, the *ReputationStorage* smart contract manages the ratings of the peer reviews, updating the rating of reviewers upon receiving new ratings if these ratings are allowed by their Paper contract. This prototype does not cover advanced reviewer interactions (register, import, search and endorse) which is the focus of the second prototype, explained in the following subsection.

5.2. A Minimum Viable Product for Reviewer Management

This functional prototype was designed with participatory methodologies (Lean Design and User-Centered Design), in close collaboration with journal editors [51]. Thus, it is designed to respond to their needs. The principal value proposition [52] for these journal editors is 1) a tool to find reviewers that 2) provides relevant metrics about them such as their timeliness or acceptance ratio, and 3) access to the open peer reviews of these reviewers. Figure 3 shows a

[7]https://github.com/DecentralizedScience/Gateway
[8]https://metamask.io

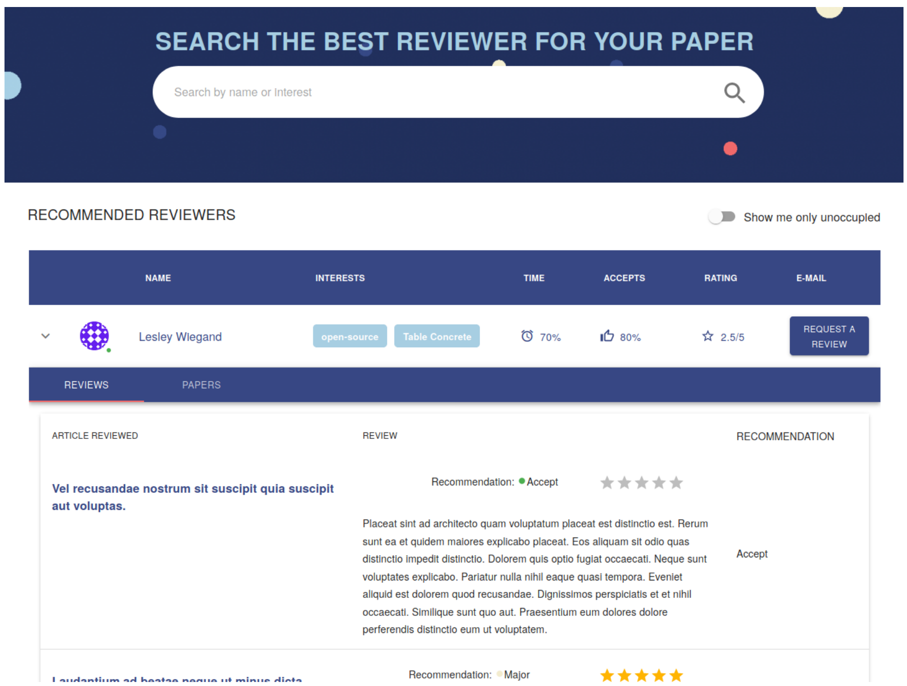

Figure 3: Decentralized Science Reviewer search GUI

detail of the Graphic User Interface (GUI). The interface allows journal editors to find relevant reviewers in the system. As further explained in Section 7.1, the prototype is integrated with the well-known publication management software Open Journal System (OJS), enabling journal editors to see the journal's reviewers, and request a review using their peer review management system. The GUI offers additional functionalities for the selection of peer reviewers currently unavailable at OJS GUI [53]. Concretely, it provides information about reviewers such as the acceptance ratio, the reputation, or the timelines, and facilitates access to their previous review reports.

However, this prototype does not just rely on centralized legacy software, but combines both centralized and decentralized technologies. In particular, (1) it uses Ethereum smart contracts to provide a decentralized management of the logic and state of the system, and (2) uses IPFS to store in a decentralized network larger files such as academic papers or the content of peer review reports.

This way, using decentralized technologies we aim to promote the transparency of the peer reviewing process (Section 3.3) and provide an open access by design infrastructure (Section 3.2) for such information. Furthermore, maximizing interoperability and decentralization, we enable the participation of other third parties and prevent the enclosure of the information in data silos or walled gardens [21].

The implemented application interacts with these decentralized technologies to store, update and retrieve the needed information about the peer reviews managed by the system. Currently, the interaction with these decentralized technologies is done via a NodeJS implementation of the public GraphQL API (explained in Section 7.2). Such implementation accesses both the existing centralized and private information of journals, and the publicly shared and decentralized information Decentralized Science promotes. Thus, the software provides a web search interface that access both centralized and decentralized data, abstracting the technological differences for a better user experience.

6. Evaluation

We have performed two different and complementary evaluations. The first one consists on a survey to collect quantitative information regarding the response of potentially interested users with different profiles in a platform like DecSci. That is, an exploratory study to assess whether our proposal would attract enough early adopters to enable further exploration and validation. The second evaluation consists on a set of interviews to better understand the problems faced by the editors during the peer review process. We also performed interviews to validate our search tool for relevant reviewers.

6.1. Exploratory study to assess the interest in our proposal

6.1.1. Goals

Assess 1) the importance of perceived issues in the current peer review process, 2) whether a reviewer reputation system might help to solve theses problems, and 3) possible resistances towards a reputation system.

6.1.2. Target population

Scholarly researchers interested in the improvement of the peer reviewing processes. We reached three different academic groups potentially interested in our proposal: "Open Science Ecosystem", a Telegram group with more than 150 members from projects that are developing decentralized and open source software for open science, the Computer Science department the authors are members of, and the 36 subscribers that signed-up to the project's newsletter at our prototype's website. Thus, the study does not aim to generalize the results for the whole academic researcher community; its purpose is just to explore the response of potentially interested users with different profiles. In particular, we are interested in collecting answers from the perspective of authors, reviewers and editors. Note that most researchers have experience in at least two of those roles.

6.1.3. Survey

The survey contains 11 sentences that must be rated using a 1 to 5 Likert scale to measure the level of agreement with the statements, where 1 means "strongly disagree" and 5 "strongly agree":

1. As an author, I think that the quality of the review process can be sensibly improved.
2. As an author, I think that the fairness of the review process can be sensibly improved.
3. As a reviewer, the recognition, reputation or rewards I receive feels fair in relation to the amount of work that I do.
4. As an editor, I have difficulties finding good reviewers (quality, relevance, timeliness).
5. As an author, I would prefer to submit my work to a journal in which reviews can be publicly rated (on a reviewer reputation system).
6. As a reviewer, I would prefer to submit a review to a journal in which my review would be publicly rated (on a reviewer reputation system).

7. As a reviewer, I would only submit a review to a journal which rates its reviews, if I remain anonymous.
8. As an author/editor/reviewer, I would like to be able to rate the reviews of the papers I am working with.
9. As an editor, I would find a reviewer system sensibly useful to find relevant, timely and/or high quality reviewers;
10. I believe that a reviewer reputation system could sensibly improve the quality and/or fairness of the peer review process;
11. I believe that a reviewer reputation system could sensibly improve the recognition, reputation or rewards I receive for my reviews.

Statements 1-4 are related to *the importance of the perceived problems in the peer review process*. Statements 5-8 assess *possible resistances for the adoption of a reviewer reputation system*. And finally, statements 9-11, measure whether the respondents believe that *a reputation system might contribute to address the problems*.

6.1.4. Results and discussion

The survey was filled out by 36 researchers and the results are summarized in Table 1. The participants seem to perceived the quality and fairness of the review process can be sensible improved. They also think that reviewers are not correctly rewarded and that it is difficult to find good reviewers, but these results are not strong as the former ones.

Regarding resistances, both authors and reviewers support the idea of a reputation system. There is more controversy regarding anonymity: 14 reviewers agree or strongly agree that they would need anonymity to participate in the system, while 22 remain neutral or disagree. All participants agree that they would like to rate reviews.

Finally, the use of a reputation system for reviewers is perceived as a relevant solution for finding reviewers, improving the quality or fairness of the process, and recognize the reviewer's work.

Statement	#answers	mean	mode
1) quality	35	4.2	4
2) fairness	36	4.4	5
3) recognition	34	2.4	2
4) finding reviewers	30	3.9	3-4
5) author resistance	36	3.9	4
6) reviewer resistance	34	3.6	4
7) anon. reviewer resistance	34	3.1	3
8) want to rate	36	4.3	5
9) improve reviewers search	30	3.9	4
10) improve quality/fairness	36	4.1	4
11) improve recognition	35	3.9	4

Table 1: Survey results using a Likert scale from 1 (strongly disagree) to 5 (strongly agree).

Overall, these results, although preliminary, encouraged us to further explore our idea and perform the interviews that we describe in the following section.

6.2. Editors interviews

After assessing the interest in our proposal, we performed some interviews to different types of editors following the Lean Startup methodology [54]. The goal of the *problem interviews* is to better understand the problem editors face during a peer review process and how they deal with them. This information is essential as a first step to define the functional requirements of our software solution. *Solution interviews*, on the other hand, are used to validate the value propositions of the different iterations of the design and development of our system with a user centered approach.

6.2.1. Problem interviews

We performed 19 problem interviews and obtained information about 5 journals, 6 conferences, 3 academic associations, 4 reviewers and 1 university press. We identified that the most important problems editors face in the peer reviewing process (the ones mentioned more frequently or with a stronger emphasis) are:

- Finding suitable reviewers for each paper.
- Getting reviewers to accept the review task.
- Receiving the reviews on time.
- Obtaining good quality reviews.

We also found out that editors use different strategies to deal with these issues. For example, a conference organizer shared that, to deal with bad quality reviews and slow reviewers, they keep a list of reviewers to avoid. And a journal editor explained that he usually needs to send at least ten invitations to get enough reviewers for a paper.

6.2.2. Solution interviews

We carried out some initial usability sessions and interviews with two potential interested organizations: Ediciones Complutense[9] and Iberamia[10]. During these sessions, they tested our prototypes and helped us to improve our search tool for finding reviewers. The current state of the tool, that was introduced in Section 5, provides three main functionalities:

1. **An interface to search reviewers** who meet some criteria.
2. **Reviewer reliability statistics** such as how often they review on time, reputation ratings and acceptance ratio.
3. **Access to previous review reports** if they are publicly available (open reviews).

We have also identified new requirements aimed at reducing even more the effort required to find suitable reviewers such as getting access to a larger pool

[9] `https://www.ucm.es/ediciones-complutense`
[10] `https://www.iberamia.org/iberamia/`

of reviewers or getting automatic recommendations. We will deal with these requests in future versions of DecSci.

7. Interoperability Challenges

The Decentralized Science system proposal, as described in sections 3 and 4, and implemented in the proof-of-concept from section 5.1, is overly ambitious. In practical terms, information systems are not built on the void, but on an existing context of platforms, technologies, third-parties and legacy systems. In fact, one of the criticisms made to blockchain and decentralized technologies is their lack of interoperability with both existing centralized systems, and other decentralized applications.

Thus, there are multiple interoperability challenges related to the Decentralized Science ecosystem:

- Integration with Publication Management Software
- Facilitate adoption by third-party web applications
- Interoperability with other reviewer platforms
- Interoperability with other blockchain applications

In this section, we explain how the architecture of the proposed system is appropriate to overcome interoperability issues in all those aspects. These will be covered briefly in the following subsections.

7.1. Integration with Publication Management Software

The submission, review and publishing of academic papers is currently supported by software Publication Management Systems. Big publishers such as Elsevier or Springer use their own proprietary software while OJS Open Source software is the most adopted solution among smaller publishers and independent journals accounting for tenths of thousands of journals[11].

[11] e.g. being used by 44% of library-published, faculty-driven journals [55]

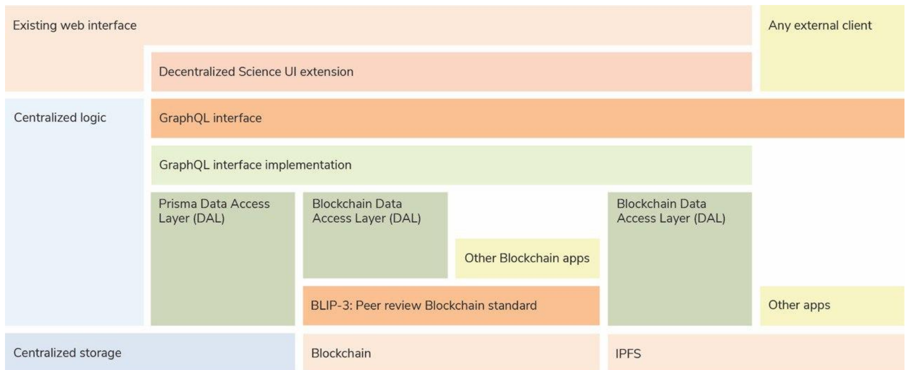

Figure 4: Decentralized Science ecosystem's architecture (With BLIP3 standard).

Our architecture proposal aims to facilitate the interoperability with such existing and widely used systems. It relies on providing a GUI for the search of relevant peer reviewers (Figure 3), which can be integrated with the publication management software as a web component. The publication management software database is accessed to get information about the reviewers The left half of Figure 4 depicts the interactions between the centralized software and storage, and DecSci GUI, logic and decentralized technologies. A public API is also provided as described in the following section.

7.2. Enabling Third-party Adoption: GraphQL Public API

Public APIs are often used by internet services to provide access and functionalities to third parties and promote interoperability among independent systems. Decentralized Science provides such API using a GraphQL interface [12]. This interface defines the data types of the system and how these data types can be composed [14]. For instance, providing the fields a peer review report record can have, or stating that users in our system have a list of such review

[12]It is worth mentioning that the project The Graph[13] is providing GraphQL APIs for existing blockchain applications [56]

[14]Details of DecSci's graphql schema can be found online in: https://github.com/DecentralizedScience/Prototype/blob/master/server/src/schema.graphql

reports that they authored. As depicted in Figure 4, this GraphQL API enables other applications to interact with Decentralized Science. For instance, other GUIs could be implemented, as well as services such as enhanced reviewer search engines.

7.3. Integration with Reviewer Platforms

The publication of peer review reports and information is a key part of large online reviewer communities such as Publons [45] (with more than 200.000 reviewers) or post-publication peer review services such as Faculty of 1000 (F1000) [57].

Our architecture proposes to inter-operate with such communities by allowing reviewers to import the reviews from Publons and F1000Research communities [15]

7.4. Interoperability with Other Blockchain Applications

There are several active blockchain projects and research that aim to share peer review information to improve recognition of reviewers' curriculum (e.g. Bloxberg's [58] peer-review-app [59]), provide incentives for peer reviewers (e.g. Eureka [60]), or enable post publication peer review (e.g. Orvium [61]), among others [62]. Several of these projects are collaborating in the definition of a standard for the registration of Peer Review information [63] in Bloxberg's infrastructure. Bloxberg is an Ethereum-based blockchain which provides infrastructure for scientific research. This standard (named BLIP-3[16]) aims to generalize the initial implementation of Bloxgerg's peer-review-app to 1) enable a diversity of actors and applications to write and read the data, 2) facilitate sharing information and avoid information silos, and 3) promote interoperability with existing standards (such as ORCID, or Crossref), decentralized applications (such as Decentralized Science, peer-review-app, PeerMiles, or Orvium), and important peer reviewer communities (such as Publons or F1000Research).Figure 4 shows

[15] The Bloxberg's blockchain peer-review-app implements such import functionality

[16] BLoxberg Improvement Proposal 3

how a shared blockchain interface would enable the interoperability of several decentralized applications.

8. Discussion and Concluding Remarks

There is a social consensus on the need to share and make scientific knowledge accessible, especially when it has been financed with public funds. Most researchers at universities and research centers do not charge for publishing their discoveries, and yet their institutions are forced to pay large amounts of money to publishers in order to access those same publications they produce.

On the other hand, the evolution of technology has facilitated the distribution and access to scientific knowledge to the point of questioning the traditional role of publishers and other intermediaries in the chain of scientific publication. In this work we have presented *Decentralized Science* (DecSci), an iteroperable platform based on decentralized technologies that aims to provide an alternative publication model to enhance the transparency and accountability of the peer review and publication processes. In particular, we propose to decentralize 3 main parts of the process: 1) the selection and recognition of the peer reviewers using a transparent reputation model, 2) the distribution of the academic papers through the IPFS peer-to-peer network, and 3) the transparency of the whole peer review process, from submission to publication, using blockchain technologies.

We carried out a short survey to tentatively assess the possible interest and resistances that a transparent reputation system for reviewers could arouse. The initial results were quite positive since most of the participants think the quality and fairness of the review process can be sensible improved and that a reputation model could be an interesting solution in which they would be willing to participate.

The core of the system is based on *smart contracts* that enforce a transparent review process, storing the different steps as time-stamped transactions in the blockchain: paper submission, review proposal and acceptance, review submission, author's resubmission of improved versions of the paper, and ratings of the reviewers. We have developed a proof-of-concept prototype based on Ethereum smart contracts to enable these interactions. We have also developed a minimum viable product of a search engine to find reviewers that provides relevant metrics such as the reviewer timeliness or acceptance ratio and offers open access to previous peer review reports. Using our web interface, journal editors will be able to find suitable reviewers in different (centralized and decentralized) platforms using a unified interface. This interface was developed in collaboration with editors of academic journals by means of different interviews to identify and provide a solution to their needs.

We have also addressed the challenges that a decentralized platform such as DecSci must face to interoperability with existing software systems. These challenges include the integration with existing publication management software, the adoption by third-party applications, the interoperability with other reviewer platforms, and with other blockchain applications.

Furthermore, the use of decentralized technologies introduces additional scalability and cost challenges. The *scalabilty* of blockchain systems is an issue in very large systems and, in fact, the Ethereum network has already experience congestion episodes, leading to dramatic increases of latency and transaction costs. However, there are currently many different approaches being developed and adopted [64] that make us feel optimistic about this issue. Besides, the Ethereum network currently handles hundreds of thousands of transactions daily, which is more than enough for our system requirements even in the long term. Blockchains are also often criticized for their transaction *costs*, but second layer solution should not only solve scalability issues in the future but also drastically reduce these costs.

Another important challenge for open and decentralized systems is the *management of identities*. Addressing potential problems by sybil identities (i.e. multiple identities controlled by a single entity) and identity verification (to avoid frauds and impersonations) are some of the most common issues to manage identities. To address them, there exist different strategies used in fields such as Social Networks [65], Internet of Things [66], distributed currencies [39], or Self-Sovereign identities [67], as well as from academic oriented services and applications such as ORCID [68], or Peerage of Science [69].

The use of blockchain technologies can also bring transparency to peer reviewing and help to expose and reduce bad practices [70] such as *fraud* and abuse in the peer review process to maximize profits [71] or benefit academic curricula [72]. However, it also introduces new concerns regarding the detection of fake identities and fake peer reviews that could break the integrity of the reviewing process, and damage the quality and fairness of academic publishing.

The low levels of *inclusiveness* and *usability* are other important limitations of current blockchain technologies. Reducing the complexities of decentralized systems to users is one of the biggest design challenges to reduce the barriers of adoption of blockchain solutions. *Data availability* and *stewardship* of decentralized information systems is an additional challenge, as without proper policies, important data could be lost.

Despite the existing challenges, the use of decentralized technologies can introduce disruptive innovations and improvements for academic publication and peer reviewing. Decentralized Science introduces a proposal of one of such systems, with a technological proof-of-concept and a minimum viable product implementations, evaluations of the proposal, and an architecture to facilitate the integration with existing and widely used technologies. The level of adoption of these decentralized technologies and their real impact remains to be seen. To support this adoption and impact of decentralized solutions, the paper introduces a perspective where an ecosystem of existing centralized technologies and emergent decentralized solutions work together to deliver the promises of blockchain applications for academia.

Declaration of Interests

The author Antonio Tenorio-Fornés is sole owner of the enterprise Decentralized Academy Ltd. Elena Pérez Tirador is hired part-time at the same enter-

prise, Decentralized Academy Ltd. The enterprise Decentralized Academy Ltd. has received EU funding (Ledger Program grant 82526) to develop the project “Decentralized Science” (`https://decentralized.science`), whose architecture and MVP prototype are shown in this research article. Samer Hassan and Antonio A. Sánchez-Ruiz are external advisors of the “Decentralized Science” project. The Decentralized Science project is a spin-off from the ERC-funded project P2P Models (`https://p2pmodels.eu`) whose Principal Investigator is Samer Hassan.

Acknowledgments

This work was partially supported by the project P2P Models (`https://p2pmodels.eu`) funded by the European Research Council ERC-2017-STG [grant no.: 759207]; Decentralized Science (`https://decentralized.science`) funded by European Union’s Horizon 2020 research and innovation programme within the framework of the LEDGER Project [grant agreement No82526]; the Spanish Ministry of Economy, Industry and Competitiveness [grant no.: TIN2017-87330-R] and the UCM [Group 921330].

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